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The Modern Macadam Road

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THE MODERN MACADAM ROAD

BY

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I recommend that the thesis prepared under my supervision by EUGENE FREDERICK MAIL entitled The Modern Macadam Road be approved as fulfilling this part of the requirements for the degree of Bachelor of Science in Civil Engineering.

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I

INTRODUCTION.

Without doubt the most important problem before the highway engineer of today is the construction and preservation of highways under the varied traffice of iron and pneumatic tires. Previous to ten or fifteen years ago road makers considered that in the macadam road they had an economic road which served as a very satisfactory route of transportation, but with the introduction of motor driven vehicles conditions began to change. Roads which previously had proved satisfactory began to disintegrate and to become a nuisance on account of the great volumes of dust resulting. Year by year the number of automobiles have increased until at present there are something like 300,000 motor driven vehicles in actual use in the United States, and the number is still increasing and more rapidly than before. Due to this increasing value of motor traffic the effect on the roads has become more and more pronounced until even the most rural roads are not free from the ravages of the automobile.

II

THEORY AND CLASSIFICATION OF MATERIALS.

In the construction of a road to withstand the automobile traffic there are usually one of three conditions to be met with.

(1) The road may be subjected to automobile traffic alone, for example speedways and race tracks.

(2) The road may be subjected to a large amount

automobile traffic and a considerable amount of light horse drawn traffic. Roadways of this kind are usually parkways and pleasure drives.

(3) The road may be subjected to a heavy mixed traffic of both motor propelled and horse drawn vehicles. This is the case of the common country or suburban highway.

The construction of the first two types of roads is comparatively easy as has been proven by many satisfactory results. It is of the third type that this thesis is to treat, and it is this one that offers so many difficulties, owing to the almost opposite effects of iron tired and rubber tired wheels.

The solution of this problem is not difficult if only durability were to be considered, since there are numerous pavements such as brick, asphalt, and wood block which will withstand the most severe mixed traffic. These pavements are, however, comparatively expensive, hence their use will not become general until their cost of construction has been materially decreased or the volume of traffic has increased to such an extent to warrant the necessary expenditure, two conditions which for most country or suburban roads are not likely to occur very soon. The solution of the problem being essentially an economic one, reverts, therefore back to the construction of a road in which crushed stone is the principle wearing constituent; since such roads can be constructed at a much lower cost that any of the above named pavements.

The success of the common macadam road depends largely on the binding action of stone dust to cement the wearing materials. This dust however is being constantly carried away by wind and water and needs to be replaced. This is done by the traffic. In a well constructed road where the stone is selected according to the amount and character of travel the dust resulting from the abrasive action of iron tires and shoes is just enough to replace that carried away by the wind and water. The road is thus automatically rebound and constantly presents a hard smooth surface. It is therefore evident that the success of the ordinary macadam road depends upon the wear of the traffic.

When such a road is subject to motor traffic new conditions are brought about. Evidently the most injurious action is the great tractive or shearing force exerted by the drivers of the car. This action does not take place in the case of the horse drawn vehicles because it does not depend upon the friction of the wheels upon the road surface for it propelling force. When an automobile passes along the road the dust is lifted by a combination of this tremendous shear ~~and~~ produced by the drivers and the vacuum created by the rapidly moving car; and when once lifted from the surface of the road it is carried away by the natural wind currents and those set up by the car itself; hence destruction of the binder is far more rapid than under ordinary conditions; and at the same time the rubber tires of the

machine produce but little if any new dust. As a result the material which is essential for the bonding of a macadam road is carried away and the stones are left exposed and subject to easy displacement, water has ready excess to the foundation, and in general the road rapidly disintegrates. Another source of injury is noticable at sharp curves. Here the centrifugal force of the heavy fast moving car sets up traverse shearing stresses which tend to tear the stones from place. This trouble can usually be easily remedied by banking the outer edge of the road but in some case this is impracticable and is in most cases rarely done.

A series of interesting experiments well illustrating the above facts were made by the United States Office of Public Roads and were in brief as follows:
A sixty horse-power car weighing with driver and mechanican 2800 pounds was driven over a level stretch of broken stone road which before the test was in excellent condition, at speeds varying from 5 to 60 miles per hour. As the car passed photographs were taken of the effect produced by the different speeds. These photographs showed that up to a speed of 15 miles per hour there was no appreciable effect, and up to a speed of 20 miles per hour no serious damage was done. With each increase in speed beyond 20 miles per hour it was evident that the larger quantity of the dust was raised by the action of the drivers.

Since the destructive action of automobiles has become so evident high-way engineers and chemists have united in their efforts to solve the problem of constructing a satisfactory road by the application of some kind of a binder to our macadam roads, but it seems that success has been the exception rather than the rule. In general the experiments have been carried out along two lines; namely (1) surface applications and (2) internal applications. The first named method may be used on either an old road or one in the process of construction; the second is applicable only during the time of constructing a new road or at the time of resurfacing an old one.

Road binders may be divided into three general classes which although distinctive in themselves gradually merge one into another. They are,

(1) Temporary binders.

(2) Semi-permanent binders.

(3) Permanent binders.

Almost without exception the temporary binders are used as dust pallatives which merely serve to keep down the dust and do not of themselves bind the stones together. They do however serve as a sort of preservative of the wearing coat by keeping it covered by a thin layer of fine material.

Semi-permanent binders are surface applied and are applied for the double purpose of preventing wear and dust, although their dust laying propensitives may be limited. Since they prevent wear of the road surface then if there is a dust nuisance it must necessarily be brought on from some outside source. These binders are always applied in a liquid form either hot or cold. As the name implies, their lasting qualities are limited. They are usually applied in the spring and should last through at least one summer season. In most cases a severe winter with heavy traffic serves to destroy their binding qualities.

Permanent binders are applied with the prime object of holding the wearing stones of the road together and thus to prevent raveling and disintegration. These binders may be applied while the road is under construction or they may be mixed with the stones before they are put in place. As the name implies their effectiveness should last as long as the wearing surface of the road. As in the case of the semi-permanent binders their dust laying qualities are limited, but for the reason that wear is reduced the amount of dust is also reduced.

Prevost Hubbard in a recent book on "Dust Preventives and Road Binders" makes the following chemical classification; which, although it does not embrace near all of the dust preventives and road binders, covers the most important ones:

I Non-bituminous materials.

1. Inorganic.

(a) Water.

Calcium chloride and other hydroscopic salts.

(b) Sodium silicate and other chemicals capable of reacting with each other or with the road fragments to form colloidal binding films. Rock and slag products.

(c) Portland and other cements.

2. Organic.

(a) Oil of aloes and other vegetable oils.

(b) Concentrated waste sulphite liquors.

Waste molasses residue.

(c) Resinates.

II Bituminois materials.

1. Petroleum, petroleum products, and solid native bitumens.

(a) Crude paraffin petroleums.

Petroleum distillates.

Semiasphaltic and asphaltic oil emulsions.

(b) Viscous crude semiasphaltic and asphaltic petroleums.

Liquid semiasphaltic and asphaltic oil residuums.

(c) Very viscous and semi-solid semi-asphaltic and asphaltic oil residuums or oil pitches.

Asphalt and other solid native bitumens of an asphaltic nature.

2. Tars and tar products.

(a) Crude water gas tars or oil gas tars.

Tar oils or distillates.

Emulsions containing tar.

(b) Crude coal tars.

Liquid tar residuums.

(c) Very viscous tar residuums.

Tar pitches.

The two general heads of this classifications are distinctive. On the other hand the sub-heads are just the opposite. There is at present almost an umlimited number of these different binders on the market and it is no more than natural that their chemical composition is somewhat of a mixture. Consequently a great many of them are compositions of two or more of these different materials and their classification is not a distinctive one.

III

TEMPORARY BINDERS.

To the division of dust preventives or temporary binders belongs water, hydroscopic salts, oil emulsions and the more fluid oils and tars. The principle object in using these materials is the abatment of the dust nuisance but in a way they also act as binders. In an ordinary macadam road if the traffic produces enough fine material no raveling or disintegration results, or if the original binder can

be retained the same is true; hence any material which tends to retain the dust is in effect a binder. The chief objection to these binders is the fact that to be successful frequent applications are necessary. If as soon as these materials lose their dust laying properties new applications are not made the destructive action begins anew and the road will ravel and disintegrate almost as quickly as before treatment.

WATER.- The use of water as a dust pallative and binder dates back long before the advent of the automobile. Its binding qualities are due almost entirely to capillarity. It is the most abundant and cheapest per unit of volume of all binders but owing to the frequency of application required and the amount necessary at each application it usually develops to be one of the most expensive, even under the most favorable circumstances. Sprinkling with water where the source of supply is distant is entirely out of the question because of the relatively high cost of transportation compared to the actual value as a binder.

HYDROSCOPIC SALTS.- The discovery that in general water was not a satisfactory dust layer led to the trial of hydroscopic salts. The value of these materials lies in the fact that they having a considerable affinity for water retain the water and keep the road in a moist condition long after water alone would have evaporated. The most important of these salts are magnesium chloride and calcium chloride.

MAGNESIUM CHLORIDE- Magnesium chloride occurs to a considerable extent in sea water. Its effect may be noticed in the tendency of the cheaper grades of table salt, made from sea water, to absorb moisture in damp weather. Due to the presence of this salt sea water has been used to a considerable extent on roads located favorable to the source of supply. Although the number of sprinklings are reduced from that of ordinary water the result obtained are far from satisfactory owing to the large amount of common salt (sodium chloride) which is present in sea water and which lacks the hydroscopic powers of magnesium chloride. In very dry weather a hard, undesirable salty scale is formed on the road and in wet weather a salty slime or mud is produced which is injurious to the iron work and varnish of vehicles and which is also likely to produce soreness about the fetlocks of horses.

In making common salt from sea water a waste product called bittern or brine is obtained. This bittern contains practically all of the magnesium chloride of common sea water but is without the sodium chloride or ordinary salt; hence it has all the favorable constituents of sea water minus most of its undesirable qualities. It therefore has greater dust laying qualities than the sea water. Owing to the fact that this waste product is useless for other purposes its first cost is very low and in localities adjacent to a salt plant its use might prove both satisfactory and economical.

CALCIUM CHLORIDE.- Calcium chloride is one of the most hydroscopic salts known. It is usually applied without the road being first swept. Usually the first few applications are on an average 0.4 gallons of a 15 or 20 percent solution per square yard. At least two applications are required in the first ten days in order to thoroughly impregnate the surface with salt. After this has been done an application of an 8 or 10 per-cent solution once in from two to five weeks is sufficient to keep enough salt in the road. In extreme warm weather the salt will dry out and it then becomes necessary to sprinkle the road with water. However the number of applications is greatly reduced because of the retaining action of the salt. The principle advantages of this material as a dust layer are that is odorless and clean. It is without doubt a good dust layer when the air is somewhat humid or if occasionally sprinkled with water in dry weather. The formation of mud in wet weather is not lessoned but this mud is no more offensive than the common variety. The principle objections for the use of calcium chloride is that it is not a true road binder and consequently the road at the end of a season is in no better condition to withstand traffic than before treatment. If the road is subjected to heavy rains a large part of the salt is washed away and a new application must be made. If the weather is dry and warm then sprinkling with ordinary water must be reverted to. As is the case of all temporary binders applied in solution the road must be near a sufficient water supply. As a

general thing the calcium chloride treatment is slightly more expensive than water treatment. Its cost ranges from 13 dollars to 16 dollars per ton. f.o.b. plant. In one case where the traffic was very heavy it had cost the season previous 3 cents per square yard to lay the dust only partially satisfactory with water. The following summer the calcium chloride treatment was used with more satisfactory results. at a cost of 2.7 cents per square yard. Six applications of the salt were made and in very dry times a light sprinkling with water was found necessary. Hence in some cases calcium chloride may prove to be economical.

OTHER SALTS.- Other salts that have also been employed to a small extent are, sodium silicate, lyminite, and potassium silicate.

NON-BITUMINOUS OILS.- The non-bituminous oils embraces the vegetable oils, and animal oils and fats. They can be classed as only preventives because they contain little if any true binding base but hold the dust by their oiling effect. Their action is very similar to that of water and hydroscopic salts except that the number of applications is somewhat reduced because they are of a less volatile nature; hence they prove effective until they have become completely saturated with dust. In wet weather these oils produce very onjectionable mud and for this reason alone they do not make satisfactory road materials. There only use is in making a soap solution to act as an emulsion for mineral oils and tars. The more important of these oils are cotton

seed oil, lindseed oil and an oil from the waste products of raw wool.

BITUMINOUS TEMPORARY BINDERS.- The only important bituminous temporary binders are the lighter oils and tars.

LIGHTER OILS.- Of the bituminous oils used as binders only the lighter and more liquid come under the class of temporary binders. The heavier grades contain asphalt in sufficient quantities as to be semipermanent in binding effects. These very fluid oils can be applied with the ordinary water sprinkler, only enough being applied at one time to saturate the dust present. A number of light applications in a season is to be preferred to one or two heavy applications; for the latter is apt to not be completely absorbed by the road, thus causing the road to present a slimy slick surface. Even with light applications the surface, unless the oil is very asphaltic will become greasy and slippery, and will cut up badly in wet weather. In localities advantageous to the source of supply roads may be treated at a cost of from 4 to 6 cents per square yard for the season. For this price roads may be treated much more successfully in other ways; hence their use is not to be recommended.

LIGHTER TARS.- As in the case of oils only the lighter tars are temporary binders. By lighter tars is meant both the crude and refined products which are fluid enough to be applied at ordinary temperatures with a common

street sprinkler. The action of laying the dust is quite similar to that of the oils. The one advantage over oils is that in wet weather no undesirable mud is produced. The best type of binders of the sort are the partially refined water gas tars and coal tars. These tars are capable of developing some degree of binding power although they will not prevent raveling under heavy traffic. The cost of such treatment is about 3 cents per square yard per season.

CONCLUSION.- This constitutes the principle materials as used for temporary binders. It is evident that as a rule their use is not satisfactory and that in none but exceptional cases is their use to be recommended.

IV

SEMI-PERMANENT BINDERS.

Binders of the semi-permanent class are applied to the surface of the road and are permitted to permeate down through the wearing coat of stones. A road treated in this manner may be either a newly constructed one or an old one which has begun to wear and must be repaired in order to prolong its life. By far the greater numbers of roads so treated are of this latter type. This is a condition of affairs which should not exist. If a road is to be treated with a semi-permanent binder it should be given a treatment at the time of construction and at all times after that when it becomes evident that the binder has lost its cementitious

powers. This is evident from the fact that at the time of construction the road is in an ideal condition to receive a binder, being free of dust, dirt, moisture, ruts and worn-out places, and presenting a surface through which the binder will permeate quickly and uniformly. However, many macadam roads were put down before the destructive actions of the automobile were evident; hence a large percentage of roads must be treated after they have received considerable wear. This same fact makes it evident that semi-permanent binders play a very important part in the preservation of our roads, for, as a general thing, permanent binders are introduced only at the time of construction. All the important semi-permanent binders owe their binding qualities to the bituminous elements which they contain. These materials consist of petroleum products, tars, and tar products. The native asphalts are seldom if ever used as a semi-permanent binder. Their building qualities are such as to place them in the permanent class. The petroleum and petroleum products are represented by the heavy semi-asphaltic and asphaltic petroleums and the liquid distillates from such oils. With the increase of viscosity and asphaltic contents and with the decrease of volatile oils they gradually merge into the permanent class. The tars and tar products are represented by the heavier crude coal tars and the partially refined tar residuums. Like the petroleum and the petroleum products they too, gradually merge into the permanent class.

PETROLEUM AND PETROLEUM PRODUCTS.- In this country unlike Europe the greater number of experiments carried on with bituminous binders have been with oil and oil by-products. In Europe the tars have been experimented with to a large extent. The preference to the oils in this country is probably due to the fact that early in the history of the problem of introducing binders several experiments which resulted in absolute failure were made in this country with tars. These failures were ~~made~~ probably due to the use of inferior tars and poor methods of application; nevertheless it is evident that in general highway engineers do not recommend the use of tars but they give the oils preference.

In the United States the first attempt to use petroleum on roads was in Santa Barbara, California with the express purpose of laying the dust. The oil proved very successful as a dust preventitive and as it contained a large percentage of asphalt it also greatly improved the surface of the road. Popular attention was aroused and soon a great many of the crude oil centers of the country were using oil on their roads. As might be expected the results varied from complete failure to excellent. Within the last few years considerable study of the possibilities of petroleum and petroleum distillates has been made and a large number of road oil industries have been developed. As yet the entire subject is in the experimental stage and much is to be learned concerning the physical and chemical properties of the different oils.

Of the several states which are striving to improve their highways Massachusetts probably leads in the percentage of total mileage improved. Out of 1,800 miles of the main road, 800 miles have been improved by the introduction of some kind of binder. As most of these roads were macadamized some years ago most of the treatment has been of the semi-permanent class.

The following table shows the average daily amount of travel observed at a number of stations for a period of one month.

AVERAGE PER DAY PER OBSERVATION STATION.

Month	Total No. Sta.	Horse Drawn Vehicles			Automobiles			Total of all kinds
		Light	Heavy	Total	Runabouts	Touring Cars	Total	
Aug.	237	83	76	159	25	90	115	274
Oct.	240	69	75	144	17	60	77	221

The roads were all of first class macadam construction and before the introduction of the motor car gave admirable service. The work of resurfacing was begun in 1908 and consisted of one of the two following methods; (1) grounting tar or asphalt in oils into the upper or wearing course, (2) by mixing tar or asphaltic oils with the stones of the wearing coat before they were spread. Following this, in most cases, a sealing coat of tar or oil was applied. Comparisons of the roads not given a sealing coat to those given a sealing coat seemed to indicate that in both methods

of resurfacing the sealing coat was necessary.

Owing to the scarcity of money the first method was used in all cases where the roads were not too badly worn. The method was as follows. The road was first patched and rolled so as to secure a true and even surface. All surplus dust and dirt was then swept off in order that the greatest possible adhesion might be secured. The binder, whether tar or oil, was then applied hot, either by gravity sprinklers or by spraying machines. The rate of application was from 1/4 to 1/2 gallons per square yard. Immediately after application sand, screened grand or stone screenings were spread on to absorb all the surplus binder. The road was then rolled with a steam roller.

By means of one spraying machine during 1909, 212,687 square yards of macadam road were treated at an average cost of 5.59 cents per square yard. In nearly all of this work asphaltic oil was used, the average quantity applied being 0.312 gallons per square yard. The covering material used consisted of sand, screened grand, or stone screenings, and was applied at the rate of 0.013 cubic yards per square yard or to an average depth 0.47 inches after rolling. The bitumen cost on an average 1.69 cents per square yard. The application of materials including heating, sweeping, watering, spreading oil, and covering material, rolling and all labor except that of screening and delivering the covering materials, cost 2.42 cents per square yard. No plant charges are included in these figures. The laborers

worked eight hours per day at $1.75; foreman $4.00; and team and driver $4.50 to $5.00. Approximately 1,050,000 square yards of macadam received such a protective coating during 1909 at an average cost of a little less than six cents per square yard. About 90 per cent of the binder used was oil containing 80 per cent of asphalt. The remaining 10 per cent of binder consisted of tar. The oil used is a residuum left after the lighter oils have been driven off. It was subjected to the following specifications.

" The oil submitted shall be of a uniform color, appearance, general characteristics and voiscosity; must contain no bodies not naturally present in an asphaltic oil; and must fulfill the following requirements. (1) It shall not contain more than 0.5 per cent of dirt. (2) It shall have a specific gravity of at least 0.97. (3) It shall not contain more than 10 per cent insoluable in petroleum ether. (4) It shall contain no body that distills at a lower temperature than 250° C. and shall not lose more than 55 per cent by weight by distillation at 360°C. (5) It shall be of such viscosity that 60 c.c. measured at room temperature, (78° F), shall when at 100° C. be not less than five minutes nor more than ten minutes in passing through a viscometer orfice 5/64 inches in diameter when acting under a head of 4 1/4 inches. (6) When 20 grams are heated in a flat bottomed dish 3 inches in diameter for 21 hours in an oven kept at a temperature of 100° C. it shall not lose more than 5 per cent by weight.

(7) Where 12 1/2 per cent by weight of material is mixed with 87 1/2 per cent by weight of sand, and briquttes made 3 inches square and 1/2 inch thick, these briquttes must keep their shape and show some binding together".

The above specifications were adopted at the beginning of 1909 where the work of the Massachusetts Highway Commission along this line had been in progress for only one season. It is doubtful if they are specific and rigid enough as to exclude some of the objectionable inferior oils.

So far the results have been very satisfactory. The asphaltic oil gives a smooth rubber like coating which becomes slippery only under the action of extreme parts. Owing to the smoothness of the surface only a very slight crown is necessary, a very desirable feature. The prime idea of the coating is to take all the wear of the traffic; hence by applying often enough the life of the road should be indefinite. If the cost does not exceed that on the 23 miles referred to, 2.85 i,e,, cents per hundred square yard, or $250.10 per mile per year providing the coating lasts two years, these experiments have practically proven that it will last at least that long, then in an economic way the road compares very favorably with any other methods of constructing and preserving a macadamized road.

The experiments carried out by the Massachusetts Highway Commission are probably the most expensive on record. Several facts are established by them and also by other

similar experiments. Before application the road must be in the best possible repair. Failure in this has been the down fall of many attempts of the preservation of macadam roads. No mere application of a binder will maintain a road in good condition. Drainage should be looked to, all holes and depressions should be filled, and the road brought to crown and grade sometime in advance of treatment in order that all repaired portions will become consolidated. This is essential because most oils used for this work do not possess enough binding power to unite the new stones with the old.

In the case of oil binders considerable dust may be allowed to remain upon the road although there is necessarily a limit to the amount. Too much dust has been the cause of many failures. A road with a considerable amount od dust on it should be swept before application. If there is a doubt as to the advisability of sweeping it is best to experiment on a short section of the road before proceeding with the work. If the oil does not penetrate the road but tends to puddle the indications are that too much dust is present.

The application of too much oil as well as too little is also a frequent source of failure. Different macadam roads require different amounts of oil. Some roads may require only 0.3 gallons per square yard of surface while others require 0.7 gallons per square yard of surface. The amount also depends largely upon the character of the

oil used. If too much oil is used the road is not economical, it is not well preserved, and in general unsatisfactory conditions exist.

The amount of moisture in the road surface at the time of application often has a marked influence upon the success of the results. This is a detail of process which has not as yet received the study it should, but it may be stated that oil should bever be applied at a time of wet weather, although a slight amount of moisture is not detremental.

A coating of sharp sand or stone screenings should be applied after the oil has penetrated as much as it will, the object being to take up all excess of oil. This coat should be rolled and in case the oil flushes to the surface additional sand or screening should be applied.

Some of the objections raised to oil treated macadam re roads are that unpleasant odors are given off, that the oil tracked into houses on pavements etc., that the particles thrown up by the wheels of vehicles are injurious to clothes; that disagreeable mud is formed in wet weather which is injurious to the varnish on the vehicles; and that the tractive resistance of the road is increased. With the application of the right kind of oil under the proper conditions most of these objections are negligable. The odors of good asphaltic residual oils are very slight and that of the lighter oils disappear as soon as the lighter constituents evaporate. The use of too large an

amount of oil or the presence of too much fine material on the surface of the road is the cause of most of the other objections. If a proper amount of sand or stone screenings are used the particles of the oiled surface will not be any more injurious to the clothes than any other dirt and should not leave a stain. The oil will probably be tracked for a short time after application but this can be remedied by closing the road to traffic. The presence of too large an amount of fine materials on the road before application is frequently the cause of a disagreeable mud in wet weather. The fine material together with the use of too large an amount of oil causes an increase tractive resistance. If proper precautions are taken and the right methods are used an oiled macadam road should be smooth, dustless, waterproof, and resilient. It should have no disagreeable odor and its appearance should be pleasing to the eye, being free from the disagreeable glare of the untreated macadam road. Extreme frost tends to break the bond and hence in localities subjected to heavy winters the oil must be applied at the beginning of each season.

TARS AND TAR PRODUCTS.- While the term tar may be applied to the distillates of various organic materials it is only those produced from coal and petroleum that are of value in the treatment of roads. In this connection the important coal tars are, (1) gas house tars, and (2) coke oven tars; and the important petroleum tars are (1) water

gas tars, and (2) true oil gas tars. Like all bituminous products the chemical and physical properties of the different tars vary considerably; hence their value as road binders varies considerably also.

As early as 1840 tar was used as a road binder in Nottingham, England but it was not until 1866 that it was first used in the United States. Since 1840 tar has found much favor as a road binder in England, France, and Canada and as a result, these countries are far in advance of this country both in regard to total mileage of roads treated and in methods of application.

As was mentioned before about 10 or 15 per cent of the roads improved in Massachusetts were treated with tars. The method of preparing the road and applying the tars was practically the same as in the case of the oils. The following are the specifications of the tar.

"Refined tar:- The tar must be uniform in color, character, appearance, and viscosity, and must have the following qualities. (a) It shall contain not more than 0.5 per cent of mineral matter or dirt. (b) It shall have a specific gravity between 1.18 and 1.25. (c) It shall contain not more than 17 per cent by weight of free cocham. (b) It shall contain no body that distills at a lower temperature than 325° C.; not over 10 percent by weight shall distill below 270° C.; and it shall contain at least 65 per cent by weight of pitch or bitumens remaining after all bodies up to 360° have been distilled. (c) When 20

grams are heated in a flat bottom dish 3 inches in diameter for 21 hours in an oven kept at a temperature of 100° C. the loss shall be no more than 10 per cent by weight. (f) It shall be of such viscosity that 60 C.C. measured at room temperature, (78°F.), shall when at 100° C. be not less than 150 seconds and not more than 450 seconds in passing through a viscometer orifice 5/64 inches in diameter when acting under a head of 4 1/4 inches. (g) When 12 1/2 per cent by weight of the material is mixed with 87 1/2 per cent by weight of sand of such a grade that all will pass through a sieve having 10 meshes to the linear inch, and practically none through a sieve with 190 meshes to the linear inch, and briquettes made 3 inches square and 1/2 inch thick, such briquettes will so harden in 7 days at ordinary room temperature that when laid flat and held by their edges by two parallel knife edge bars they shall not bend when a weight is suspended from a third knife edge or parallel bar placed across their center, until this weight reaches 200 grams, and the weight causing bending shall not be greater than 80 per cent of the weight causing breaking".

The tars supplied conforming to these specifications have so far given very good results. The specifications appear to be more complete and less open to criticism than those for oils.

In the treatment of a road with tar the tar should in almost every case be heated to a temperature of about 100°C. The method of application as used in this country and formerly in European countries is as follows. The road surface is first thoroughly swept in order to remove all

dust and dirt. The heated tar is then spread on and thoroughly broomed in. Following this the road should be closed to traffic and the tar allowed to remain unmolested for at least 12 hours in order that it may have time to soak in. At the end of this time a coating of clean sharp sand or stone screenings should be applied so as to absorb the excess tar. The surface should then be thoroughly rolled in order to compact the surface. The sweeping of the road is frequently done by hand, but if an ordinary street sweeping machine is used the work may be done more rapidly and economically. Usually the tar is heated in an open kettle mounted on wheels and fitted with a portable fire box. If the kettle is kept just in advance of the work the tar may be run out upon the road as required by means of a hose. By using two kettles the process may be continuous, one being in use while the other is being charged and heated. Owing to the time and expense incurred in applying tar from kettles it is advisable to use sprinkling tanks as spraying whenever possible. The valuable feature of the spraying machine is that the tar is sprayed upon the road with sufficient force as to need no brooming. There are several kinds of such patented machines in use in England and France but as yet very few of them have been introduced into this country. If the tar kettles are used laborers with long handled brooms, similar to the ones used in street sweeping, follow the tar spreaders and thoroughly broom every portion of the road surface. In this way the

excess tar can be pushed ahead and used in covering fresh places.

In case it is impossible to keep traffic off the road for twelve hours one of two methods may be used. Either one half the width of the road can be covered at one time this allowing the other half to be open to traffic, or the coat of sand or stone screenings may be applied immediately after the application of the tar in a sufficient quantity to prevent the tar from sticking.to the wheels of vehicles. The first method will undoubtedly give more lasting results but much care must be taken or the overlapping joint may in time produce a seam along the center of the road. When the second method is used there is danger that the tar will be absorbed by the loose material rather than by the road proper, resulting in a poor bond.

One of the most common causes of the unsuccessful treating of roads with tar is the failure to remove all dust and loose material from the road surface. Tar will not penetrate through a layer of dust and penetration is essential for success.

Whenever any repairs are needed on a tar treated road they should be made at once for if disintegration once sets in it spreads very rapidly. Under favorable conditions a surface treated with a heavy tar should last a year without requiring any repairs although in many cases within a few months after application the tar disintegrates and rapidly disappears under the action of rain and traffic.

In a case like this a slimy mud is formed in wet weather and a fine black initating dust in dry weather. The fault usually lies in the method of application or the quality of the tar. It is the use of such workmanship and tars which has prejudiced people against the use of tar as a road binder. There is one objection to tar treated roads that is undoubtedly justified, viz., in frosty weather the road becomes quite slippery.

The amount of tar required to treat a road depends upon the absorbing powers of the road and the fluidity of the tar when applied. The amount may vary from 0.30 to 0.70 gallons per square yard when the application is made by hand. By the use of a spraying machine as small an amount as 0.21 gallons per square yard has given good results for first treatment. In all cases as the number of applications increase the amount of tar required decreases.

The worst enemies of tar treated roads are decayed vegetables, prolonged rains and frosts. The trouble arising from decayed vegetable matter may be entirely overcome by keeping the road surface free from all sticks and leaves, but prolonged rains and frosts cannot be done away with. In localities subject to continued rains or the alternate freezing and thawing of spring the tar surfaced road is likely to rapidly disintegrate although the drainage may be excellent. In such a locality a surface treated tar road is not to be recommended.

The cost of a road treated with a semi-permanent tar binder varies with the different conditions. In France the cost for machine application is about 3 cents per square yard per year and for hand work about 5 cents per square yard per year. In the United States the cost is seldom less than 6 cents per square yard per year and may run up as high as 12 cents. The higher cost in this country is probably due to poor conditions of the road before treatment which necessitates the use of more tar and more surface dressing, and the higher price of labor. Judging by the results obtained with surface applications of tars it is doubtful if an expense of over 5 cents per square yard per year will prove economical.

CONCLUSION.- The semi-permanent binder offers the only satisfactory method of the preservation of macadam roads constructed before the introduction of the automobile. If either a newly constructed road or an old one is treated with a semi-permanent binder and the proper degree of care is taken sufficiently satisfactory results can be obtained to warrant the expense involved. Like all binders the cost of application is in many cases prohibitive but taken as a whole this class of binders give more satisfactory results than any others.

V

PERMANENT BINDERS.

All binders of the permanent class are bituminous in nature. No other material has been discovered which will retain its binding powers long enough to be classed as a permanent binder and at the same time be satisfactory. in other respects. The materials which have been at least partially successful along this line are oils, tars, native asphalts and rock asphalt.

A successful application of a permanent binder can be made only at the time of the construction of the road. In a very few cases this class of binders has been attempted at the time of resurfacing old roads but without great success. Probably a semi-permanent binder would have been more successful in these cases.

These are two general methods employed to introduce bituminous elements into a macadam road;
1. penetration method, and 2. mixing method.

PENETRATION METHOD.- The general characteristics of the penetration method is as follows: The road bed is first shaped and rolled as in ordinary macadam construction. A course of crushed stones ranging in size from 1 1/4 inches to 2 1/2 inches is laid loose to a depth form 5 to 6 inches. This is thoroughly rolled and sand or stone screenings are then applied until a firm,sound surface is presented. This course, although presenting the appear-

ance of a nearly completed road, is to serve only as a foundation for the bituminous concrete. The filler serves the double purpose of making the foundation solid and of cutting off the flow of bitumen. A real smooth surface to the foundation is not desired as the presence of two much fine material will prevent the formation of a good bond between the two courses. The second course consists of stones from 1/4 to 1/2 inch in diameter laid on this foundation to a depth of 2 1/2 inches and well rolled. Next a light coating of clean 1/2 inch stone chips is applied and rolled into the surface. This coating should not be heavy enough to fill all voids in the surface for then the bitumen will not penetrate. The binder, heated until very fluid, is then sprinkled or poured over the road at the rate of 1 to 1 1/2 gallons per square yard. No definite amount of binder can be specified since the amount required varies for each particular place. The stones of the upper two inches must be covered completely. Clean stone chips are then applied and the road is again rolled. A sealing coat of binder is then painted or sprinkled upon the surface at the rate of from 0.3 to 0.5 gallons per square yard. Another coat of screening ranging in size from dust to 1/2 inches is then applied to fill all surface voids and take up any excess binder. The road is then completed by another rolling but should not be thrown open to traffic for a few days in order to allow the binder to set.

The object of the penetration method is to construct a bituminous macadam road without using machinery or labor for mixing the ingredients. The principle disadvantages of the method are; 1. The uncertainty of obtaining a uniform distribution throughout the wearing course; 2. Lack of uniformity of the mineral aggregate; and 3. The necessity of employing a binder of softer consistency and lower mechanical stability than is desired for a permanent matrix. Of these objections the first is the most serious, since the relative position of the stone may be such that the binder will drain away from some places and pool in others. A few damp stones or a little dust may have much the same effect. If the binder is not hot enough or the road surface is cold penetration may be cut off by the binder cooling too quickly. Although the utmost care may have been taken, there is no way of telling that a uniform distribution has been obtained. As the road is subjected to travel soft wavy place will develop where there is too much binder and raveling and disintegration will set in where there is a lack of binder. If the binder has not entirely penetrated the road will become soft and sticky in warm weather and in cold weather it is likely to peal off under the action of traffic.

Lack of uniformity in the mineral aggregate except as effecting the distribution of the binder produces no results more serious than in ordinary macadam. Nevertheless uniformity is to be desired.

A binder of the desired consistency can be obtained by a proper selection. Such a binder should but barely flow when cold.

Although many objections have been raised against the penetration method it undoubtedly has some advantages over the mixing process. The principle one of these is cheapness. Under favorable conditions a satisfactory road can be produced for light traffic. If the binder is applied in warm dry weather it is quite possible to obtain a uniform distribution. Work of this kind costs but a few cents per square yard in addition to the price of about two gallons of binder, above that of a regular macadam road. providing that it is carried on with modern heating and spreading machine.

MIXING METHOD.- In the mixing method the process of making the foundation is exactly the same as in the penetration method. The wearing course is laid to a depth of from 2 to 2 1/2 inches. This coat is composed of carefully graded stones mixed with a hot bituminous binder. The mineral aggregate may or may not be heated before mixing with the binder. If the stones are heated a binder of high consistency may be used while if not the binder should have about the same properties as in the penetration method. The heated aggregate is to be preferred. The mixing may be done either by hand or by machinery. When the coated stone has been laid it is rolled either with or without the addition of a thin coat of clean stones chips. Where it

is possible to do the former without the stones sticking to the roller the surface should be completed by the addition of a light coat of binder covered with sand or stone chips; this in time being rolled and dusted with stone chips. In the latter case all surplus screenings are brushed off and a coat of binder is painted on at the rate of 0.3 to 0.5 gallons per square yard. After the screenings are again applied in a large enough quantity to take up the excess binder. The surface is then again rolled.

Without doubt the mixing method gives a better constructed road than the penetration method but the latter may often be successfully used where the traffic is light. The cost of the former is considerably higher than the latter.

CHARACTERISTICS OF BITUMINOUS MACADAM.- A well constructed bituminous macadam road should have the appearance of a mosaic with the larger stones predominating. The road should be resilient, firm and waterproof. The surface should present an even appearance but should not be so smooth as to be slippery. The road should be as dustless as an asphalt pavement. Tractive resistance is less than in an ordinary macadam road. Although the binder takes but little of the actual wear it acts as a cushion and keeps the stones from wearing one upon another. Within a short time after being laid all odors of an objectionable nature

disappear. The most critical period of the road is within the first three months after being laid. Within this time any needed repairs should be made immediately for unless all weak places are mended at once rapid disintegration sets in.

ROCK ASPHALT.- Rock asphalt is the term applied to a variety of sand stones or limestones saturated with maltha. In the construction of a road of this material the subgrade is prepared as in the ordinary macadam road. Rock asphalt should then be applied to a depth of 1/2 inch. This should then be thoroughly rolled into the upper course of the foundation. Next a coat of 1 inch of rock asphalt is applied which is treated in exactly the same way as the first. This completes the road. The best results can be obtained in warm weather. The stone of the wearing coat should be clean and dry in order that proper adhesion may be had and of a uniform size so that the asphalt will be forced into the voids. When the natural rock asphalt is close at hand the cost of constructing such a road is but little more than an ordinary macadam road. When the source is some distance away the road is not economical because the material contains 90 to 94 per cent of sand and this raises the freight out of proportion to the cost of materials. A properly constructed rock asphalt road will undoubtedly prove satisfactory if built near the source of supply.

CONCLUSION,- As far as results obtained are concerned the permanent binder gives the most satisfactory road of all binders, but the high cost is such as to make the road a paying proposition only in cases where the traffic is exceedingly heavy.

VI

GENERAL CONCLUSION.-

The proper construction of our future highways presents a problem that cannot be solved in one day. Many materials used as binders and many methods of constructing the road with the use of these materials have been tried with varying success. In one case a road constructed with a certain binder may be an absolute failure while in another under what appears to be the same conditions of traffic and the same method of constructionthe road may almost reach perfection. It is to be hoped that soon a method of road construction will be discovered which will be as much of an improvement over present methods as the macadam road was over the natural soil roads.